Investigation of an Air Cooling Process for Static Transformers

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INVESTIGATION OF AN AIR COOLING PROCESS
FOR STATIC TRANSFORMERS.

A THESIS

presented by

E. J. Carroll.

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to the

PRESIDENT and FACULTY

of the

ARMOUR INSTITUTE OF TECHNOLOGY,

For the degree of Bachelor of Science, in Electrical Engineering,

having completed the prescribed course of study in

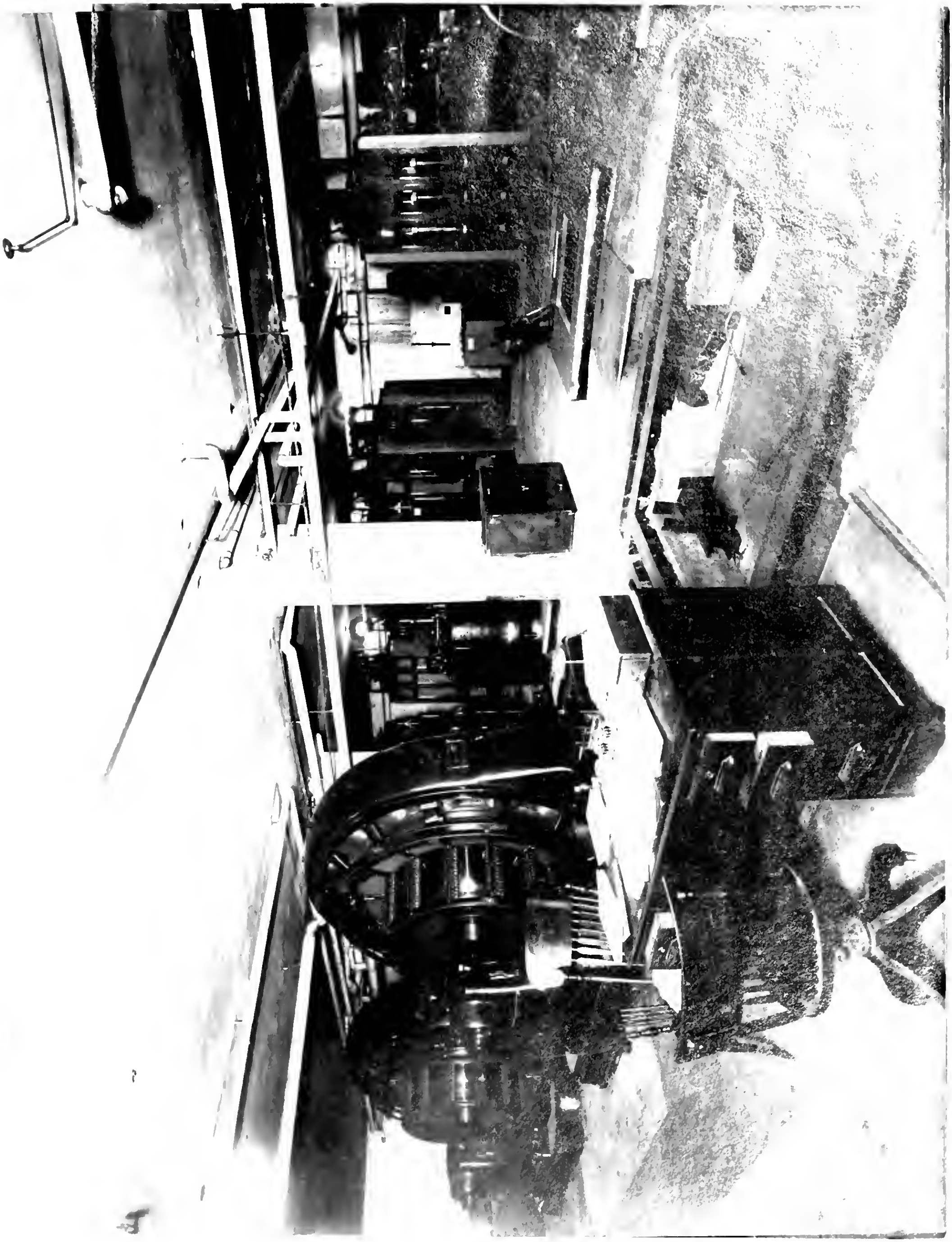
Electrical Engineering.

Chicago, June 16th, 1905.

C. E. Freeman per Snow

H. M. Raymond
Dean of Engineering Studies

L. C. Monin
Dean of Cultural Studies



INVESTIGATION OF AN AIR COOLING PROCESS FOR STATIC TRANSFORMERS.

The tendency in modern practice, towards a small number of large generating and transforming units, rather than a large number of smaller capacity, makes the necessity for some form of cooling apparatus very apparent. Especially is this true in transforming apparatus. It had been the custom formerly to use a large number of small transforners. The heat due to the losses was then easily taken care of by radiation from the transformer case, since the radiating area of the case and the watts to be dissipated were within a reasonable value. The advent of large units has made the ratio between the energy to be dissipated and the radiating surface prohibitive, so that some auxillary means of cooling must be employed. Two methods are common, one, the using of oil to surround the core, the heat being removed from the oil by means of streams of cooling water pumped through coils of small pipes placed in the oil. Another and more common method is the placing of the trans former over tunnels into which a fan discharges, allowing the cooling air to rise through the transformer dissipating the energy lost in heating, and thus keeping the iron and copper at any desired temperature determined by the amount of air sent through. It was upon the latter type of appar-

atus that the test was made.

The test was carried on at the Jackson Boulevard Sub-station of the Chicago Edison Company, situated in the basement of the Railway Exchange building. At this time this sub-station represents the latest and best equipment at the command of an enterprising Central Station Company. At present, its maximum normal output is 8,000 amperes at 250 volts; the installation at present consists of two 1,000 Kilo-watt General Electric Co. rotaries and the accompanying complement of air-blast transformers etc.. Room is provided for the future installation of three more similar units and subsidiary apparatus.

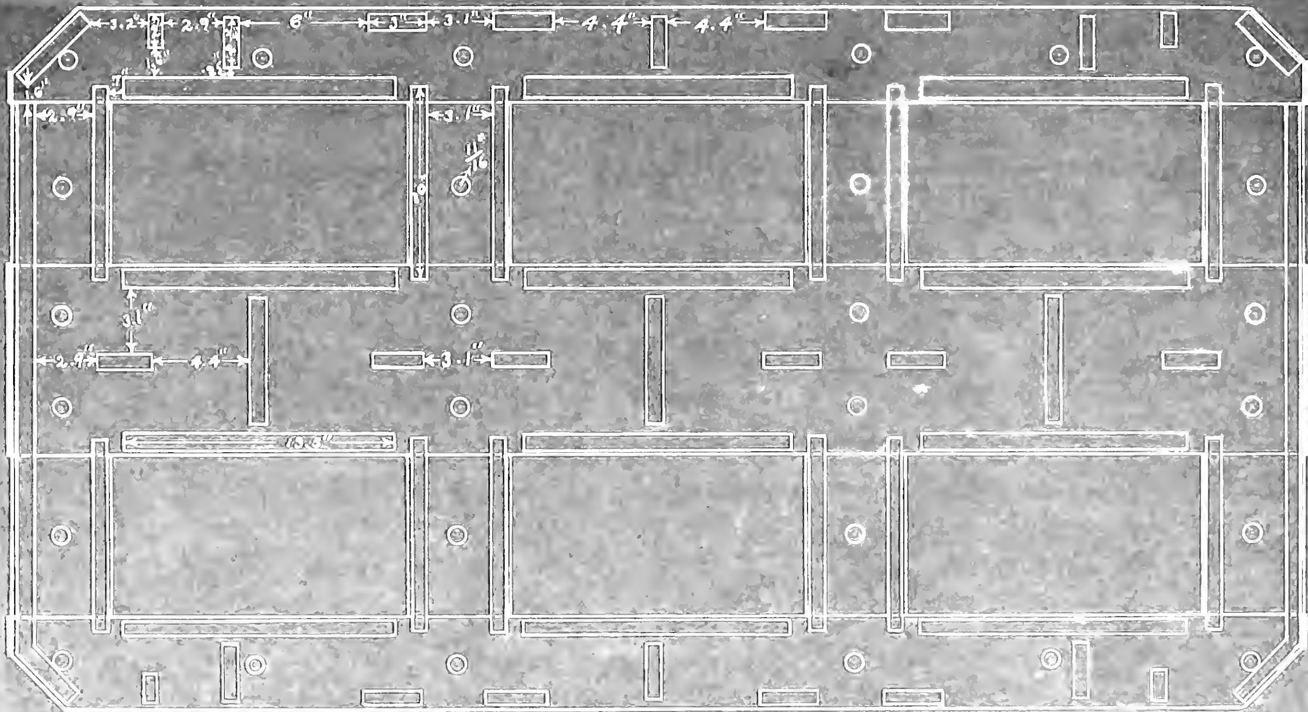
From the accompanying blue-prints an idea of the ground plan and arrangement of the sub-station can be gained. The rotaries are placed in a north and south line through the center of the station, and immediately to the rear, and parallel to them are the banks of 1,100 K.W. transformers and the regulators. It will be seen that at the present writing only units number two and three are installed, and it was upon unit number three that the test was made, it being more favorably situated for the undertaking than unit number two, due to the fact that variations could be made in the amount of cooling air without interfering with the other unit carrying the sub-station load.

The particular transformer #277809, under consideration was erected by the General Electric Co. of Schenec-

Floor Plan and Tunnels
Jackson Blvd. Sub-Station
Chicago Edison Company
22' To Wall
18' To Sw. Board
Rotary Air Duct.
Rotary #3
1000 K.W.
14'6" To South Wall
14'6"
15'
15'
15'
65 1/2' To North Wall
Unit #1
Unit #2
Unit #3
17'1"
℄ of Duct
Transformer
110 K.W.
℄ of Duct

tady, New York. It is of 1,100 K.W. capacity, at 25 cycles, and will transform from 4,500 or 9,000 volts primary to 186 volts depending on the connection. The requirements for cooling, state, that not less than 3,800 cubic feet per minute be employed, at a pressure of .75 of an ounce per square inch; nevertheless it might be well to state here that it was found that in reality over 6,000 cubic feet per minute at a constant pressure of 1.57 ounces were used. The transformer is connected delta for the three phase current on the high side, and star connected for six phase current on the low side, where connection is made to the rotary.
A plan view of the iron core showing the spaces for ventilation and positions of the coils can be seen in an accompanying blue print. The air rises along the side of the transformer between the case and the core, and then passes in a horizontal plane to the grating on the side, where it is discharged into the room. The main purpose of this air is to cool the iron core, another outlet being provided in the top of the transformer in order to allow the remaining portion of the air to escape which dissipates the energy loss due to the current flowing.

Since the allowable temperature rise in a transformer above a room temperature of approximately 25^{o} C. is 40_{o} C., by measuring the temperature of the incoming and discharged air and knowing the load for any particular period, the proper amount of air to be used can be ascertained. This was one of the features of the test.



½" x ⅜" ⅝"

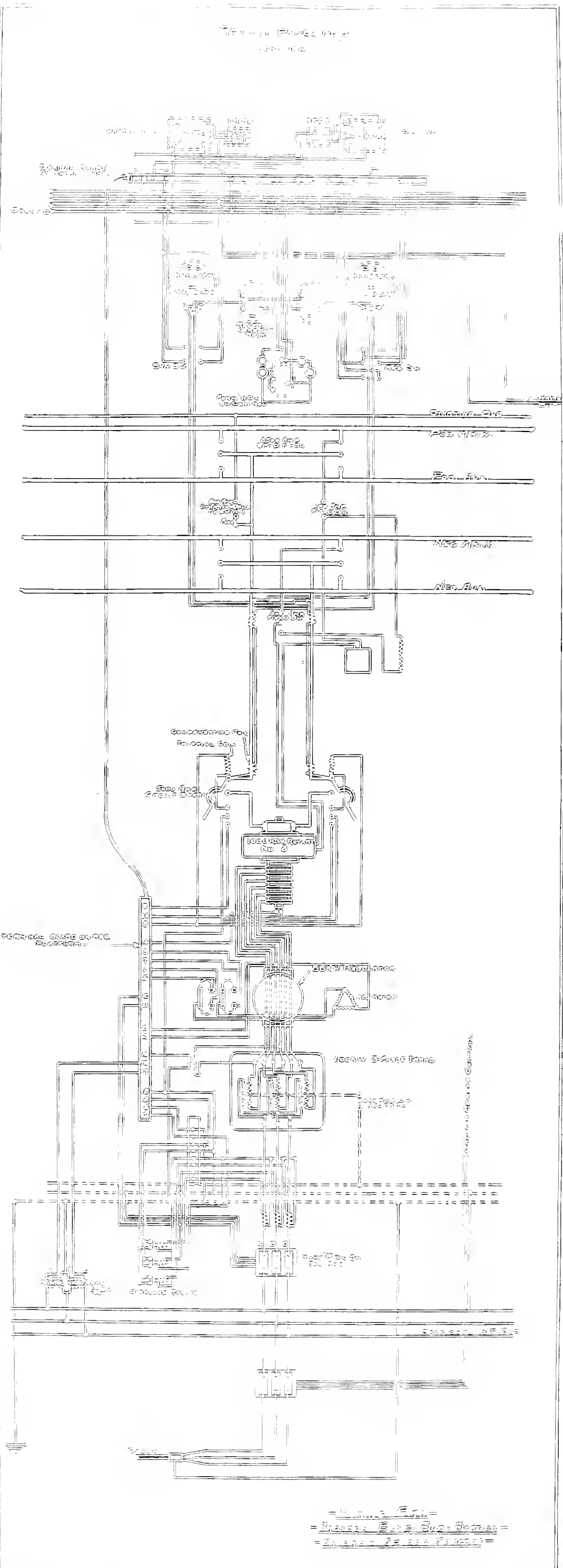
Scale 1⅝" = 1'

Plan ...

Air ...

The energy received from the generating station after passing through the switching apparatus goes through the transformer, and then through the 88 K.W. regulator to the rotary, where it is converted into direct current. Pressure leads are also taken from between the transformer and rotary to the regulator, by means of which the amount of power delivered to the rotary, can be varied, and thus the direct current pressure can be raised or lowered. After passing through the rotary the energy, now in the shape of direct current, passes to the switchboard, where it is distributed to the various feeders in the district, and subsequently to the customers. A detailed wiring plan of the transformer, rotary and switchboard wiring accompanies the report, thus obviating the necessity of a detailed explanation.

The blowing equipment consists of two Andrews and Johnson Co. blowers, run at 300 revolutions per minute, by two General Electric Co. D.C. motors. The motors are of 35 horse power capacity, at 250 volts, and run at 600 R.P.M. The fans proper are situated in the tunnel in the sub-basement, the motors being placed on a framework above the sub-station floor, and belted to the pulley on the fan. As has been stated two duplicate fans and motors are installed, so that the continuity of the blowing system is insured at all times, although from a no air test made, it was found that in case of a complete breakdown of the apparatus the transformers could be run for about two hours,

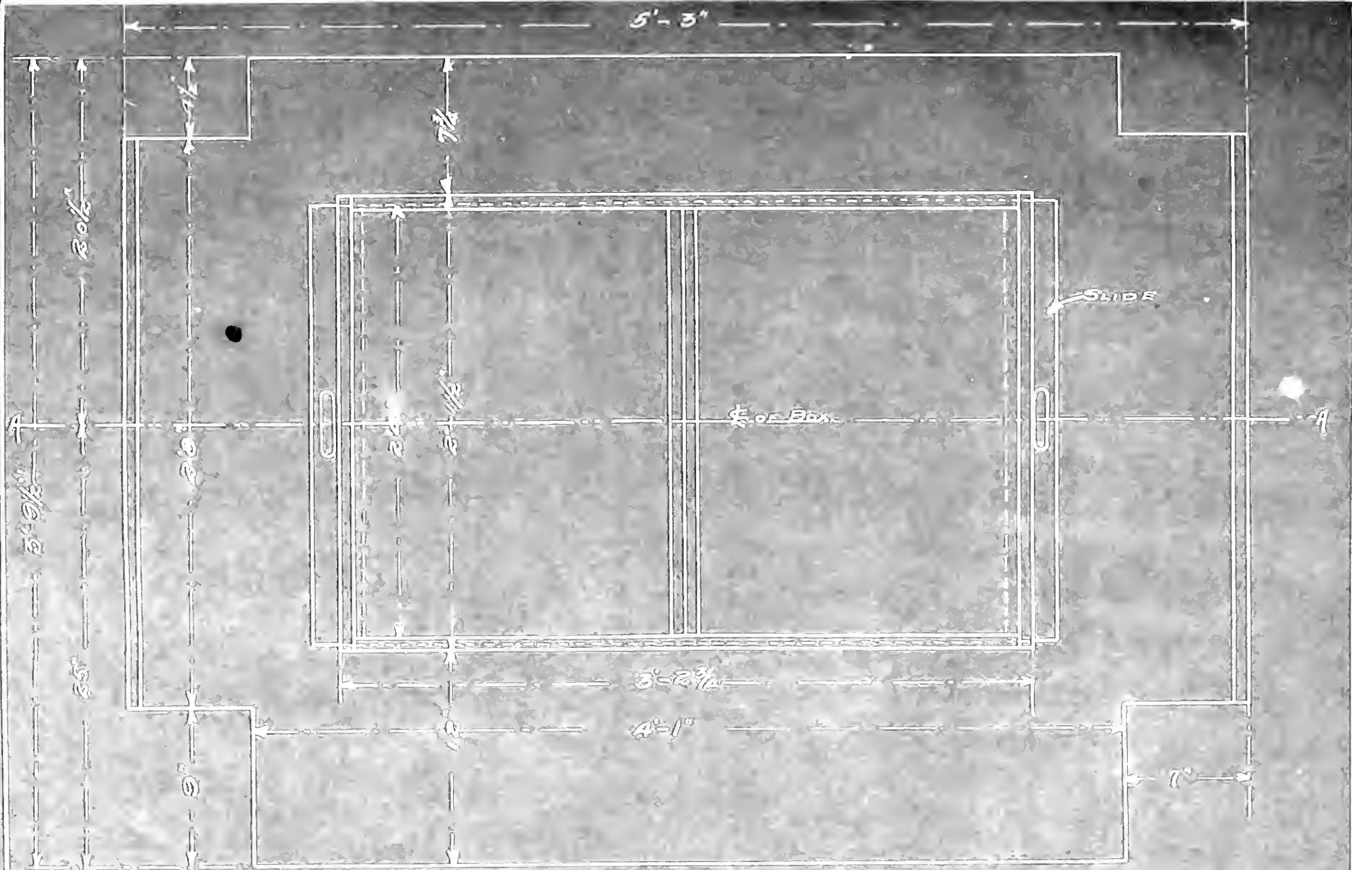

Pos. Main
Eq. Bus
Neg. Main
Neg. Bus
5000 Amp. Circuit Breaker
1000 KW. Rotary No. 6
Reactor
Terminal Board on AC Platform

under full load without any damage, and with a maximum temperature rise of about 32° C. in the iron, if the transformer was cold at the start.

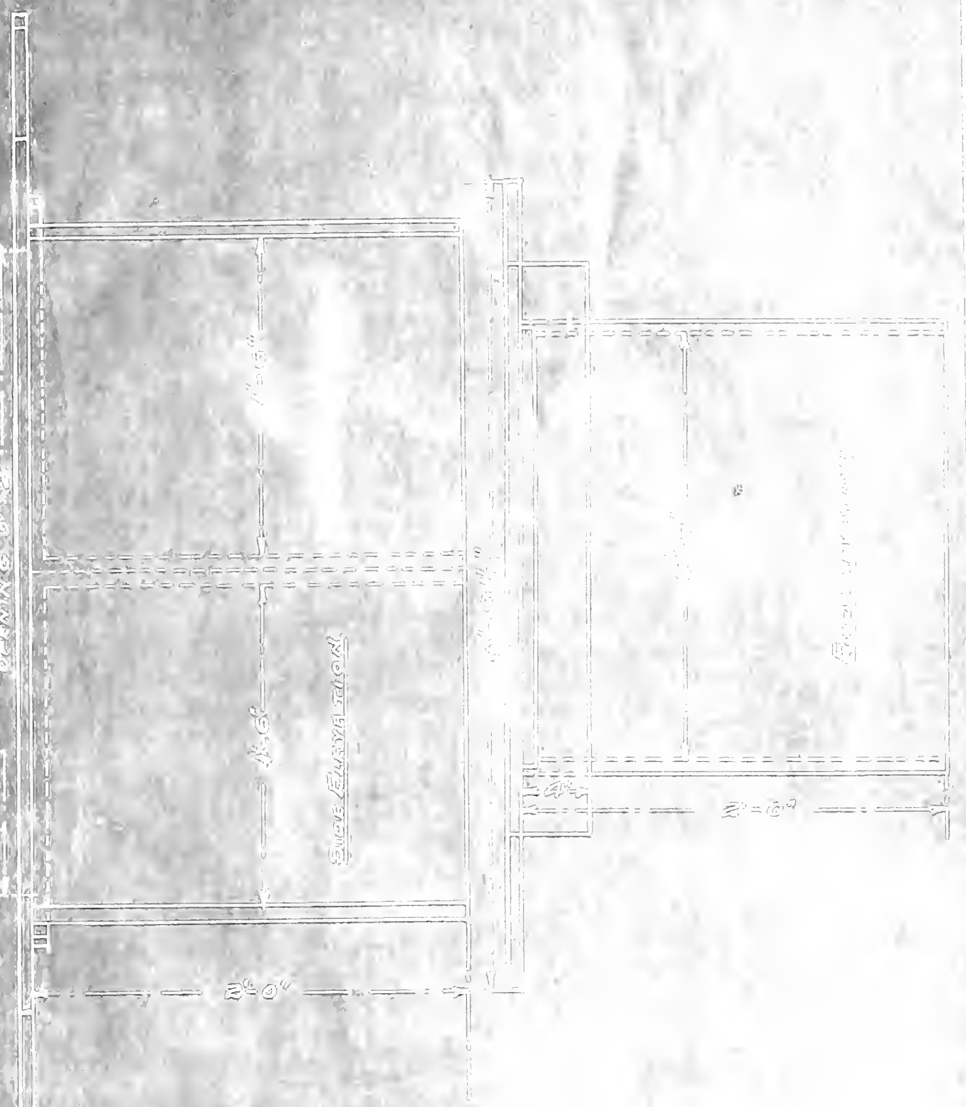
The air tunnels located below the sub-station floor are arranged so that the main shaft is at right angles to the shaft into which the fans discharge. The transformer opening is located in the roof of the main tunnel, which besides allowing for the passage of the cooling air also permits the examination of the transformer connections. Small ducts also lead both to the rotary and to the regulator; the rotary duct being separate, while the regulator duct is an integral part of the transformer duct.

In order to vary the size of the opening, and thus obtain a wide variation of the amount of cooling air special gates were constructed beneath the transformer, and built so that the entire opening could be closed if so desired. The gates were of such a form that although various openings were possible the general shape of the opening was rectahgular. The width was a constant factor, and the length of the opening was varied by varying the distance between two movable partitions. The accompanying blue prints, showing the plan and end views of the gates as constructed, will give an idea of its general shape, and of the detail dimensions.

Chief, among the smaller apparatus used in connection with the investigation was the set of Pitot tubes. These were made of one quarter inch brass tubing, and cut



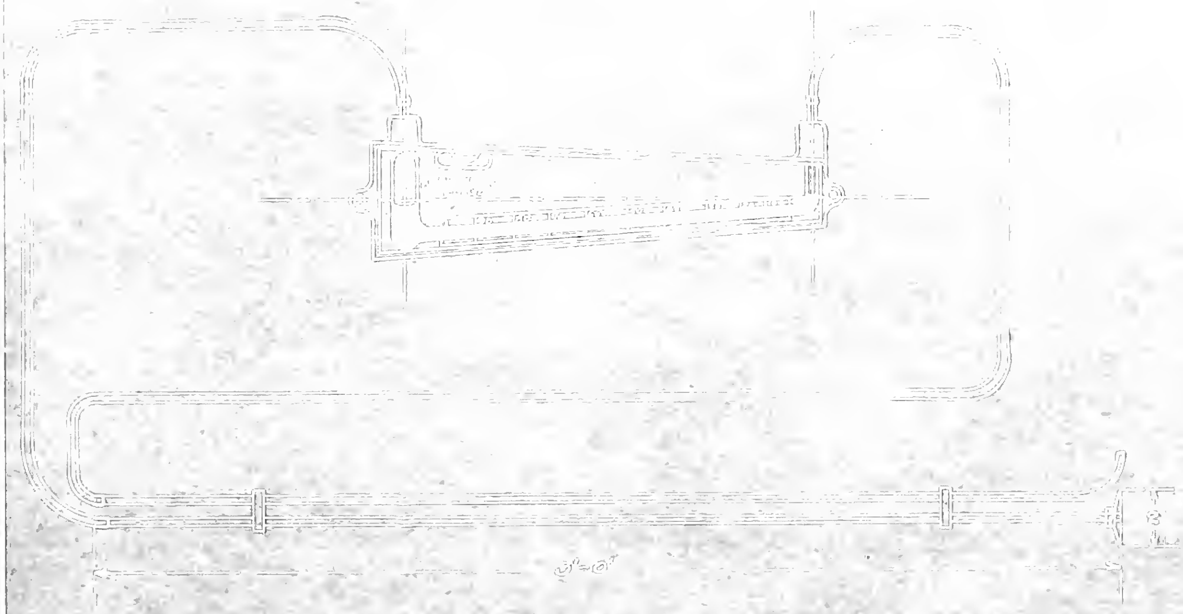
PLAN VIEW - CLOSURE FOR AIR DUCTS.
JACKSON BLVD. SUB-STATION
CHICAGO EDISON COMPANY
SCALE 1/8" - 1"



Side View Closure For Air Ducts
Jackson Blvd. Sub-Station
Chicago Edison Company
Scale ½"

three feet long. In order to measure the velocity of air two tubes are necessary, as shown in the accompanying blue print. One tube is bent at one end through ninty degrees on a two inch radius, and this end was sharpened to an edge. On the end of the other, a thin two inch disk was sweated, and turned down from one eighth of an inch at the center to a sharp edge. Two small brass blocks were then slipped over the tubes so that they were rigidly bound together in such a way that the face of the disk was held on the same level as the center of the opening in the bent tube.

The following fundamental principle underlies the use of the Pitot tubes. When they are placed in a current of air in such a way that the face of the disk is parallel to the flow and the opening of the bent tube is toward the current, the pressure in the straight tube is that due to the static pressure of the surrounding air, the disk serving effectually to keep the air from eddying in the end of the tube, or being affected by any pressure due to the velocity of the air. The bent tube is turned so that the open end is directly against the current, the thin edge dividing the air and preventing eddying around the opening. The pressure in this tube, since the air is not allowed to flow through it, will be that of the static tube plus an additional amount due to the impact of the air, and is commonly termed the velocity pressure.



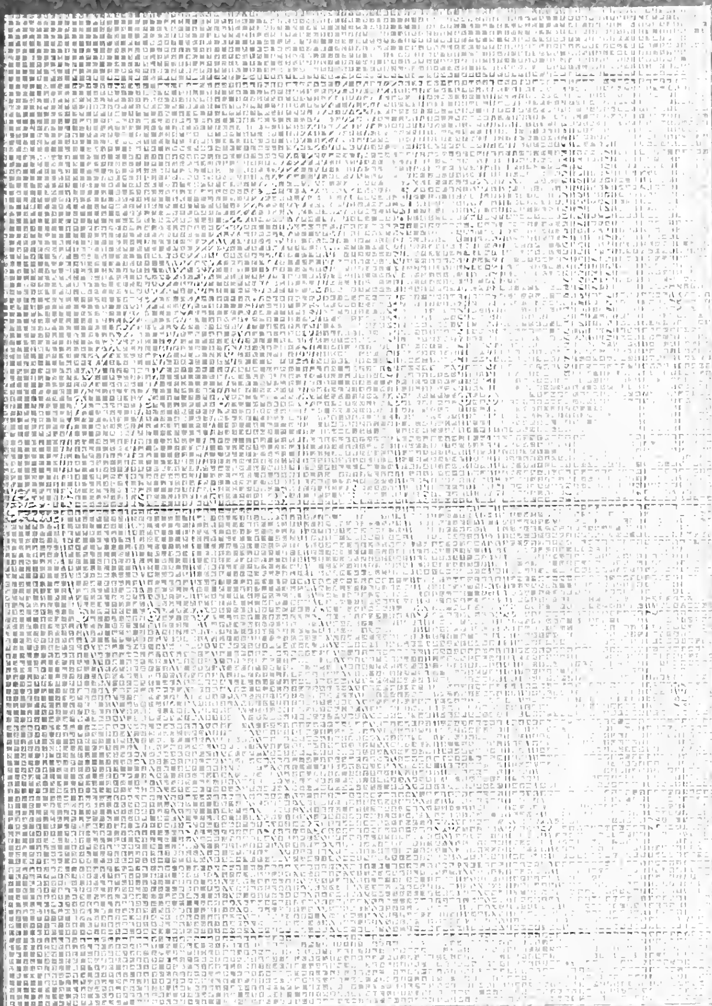
EAMES DRAFT GAUGE AND PITOT TUBES
FOR
DETERMINING THE VELOCITY OF AIR
SCALE 1-5

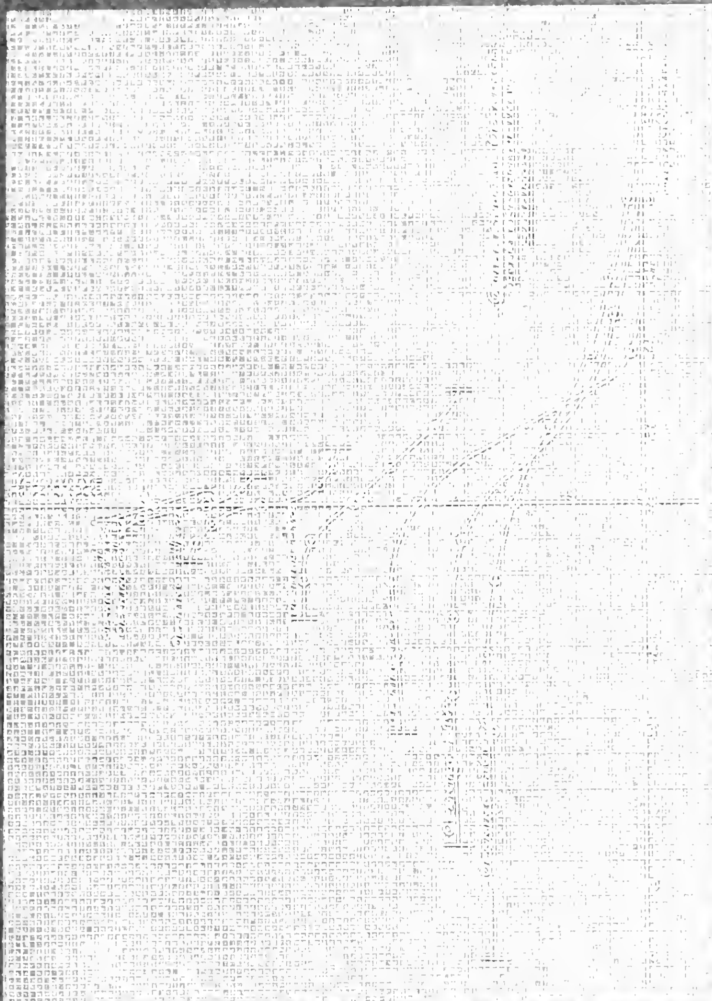
In order to separate these two readings, and thus obtain the pressure due to velocity alone, the opposite ends of the tubes were connected to an Eames differential draft gauge, by one quarter inch rubber tubing, as shown in the blue print.

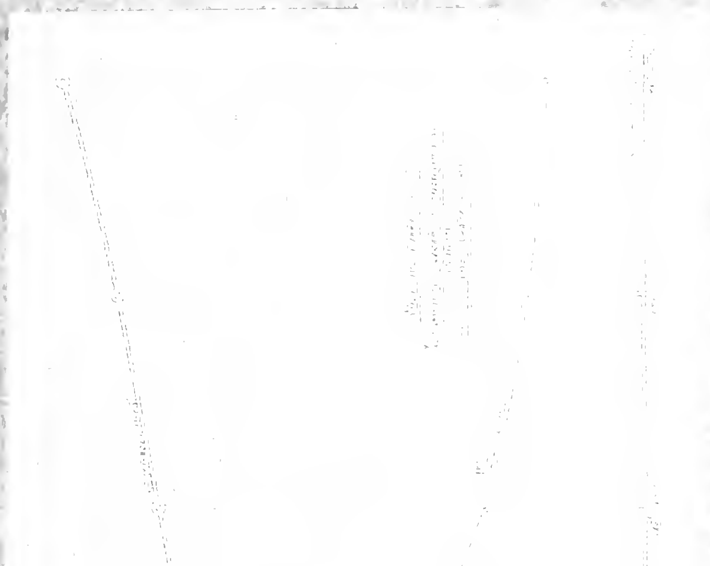
The principle of this gauge is that of a "U" tube, and can be read to one hundredth of an inch accurately, and can be estimated to one thousandth of an inch, the reading being direct in inches of water. Since the bent tube is connected to one end of the gauge, and the static tube to the other, the reading observed is the pressure head due to the difference in pressure mentioned above, that is the velocity head direct in inches of water. This may then be converted into an equivalent head, in terms of feet of air. Now it has been found experimentally that this velocity in feet per second is that which a freely falling body would have, and can be determined from the equation, $V = \sqrt{2gh'}$, where "g" is the acceleration due to gravity, or 32.16 feet per second per second, and "h'" the head of air in feet.

In order to make use of the gauge reading direct the ratio of the weight of one cubic foot of air to one cubic inch of water is introduced, and the equation then becomes:- $V = \sqrt{2gh\ R}$, where "R" is the ratio as determined above corrected for certain definite experimental conditions, and "h" the head of water in inches.

The average velocity over the various orifices used was determined by obtaining representative readings over the entire area and determining the average by means of a planimeter from the areas of the curves plotted with the various readings for one opening. This average velocity times the area of the orifice gives the rate of air supply to the transformer for that particular condition. In this manner the accompanying calibration data, and curves showing the movement of the air in the various orifices, were obtained, as was the variation of the average velocity and quantity of air with the size of the orifice. In the curve sheet showing the velocity readings in a transverse section, the points plotted represent velocity in feet per second in the central plane, with various sized orifices. This curve shows the increase of friction, at the sides with increase of velocity. The curves representing the average longitudinal velocities show the effect of the direction of the air in the duct, that is the inertia of the air as it swings up through the orifice causes the larger part to pass up the farther side of the orifice, and hence the velocity at this point is greatly increased, while that on the side nearest the blower tends, especially in the case of the larger openings, to approach zero as a value. In case of the smaller openings the effect of the vertical height of the opening becomes manifest, thus causing the velocity to become more nearly a constant







Data

for the

Calibration of Full Opening, 36" x24".

Test made May 10,1905.

Temperature in Intake 12.8°C. In Duct 19.1°C.

Barometer in Intake 29.37 in. In Duct 29.56 in.

Psychrometer - Wet 58.0°F.- Dry 66.5°F. Humidity 59.4 %.

Velocity Head (Inches of Water)				Velocity (Feet per Second)				Average Velocity
a	b	c	d	a	b	c	d	abcd
.106	.096	.100	.100	21.9	20.8	21.2	21.2	21.2
.100	.098	.110	.093	21.2	21.0	22.3	20.5	21.2
.110	.100	.110	.093	22.3	21.2	22.3	21.2	21.7
.105	.097	.130	.105	21.8	20.9	24.2	21.8	22.2
.095	.092	.100	.105	20.7	20.4	21.2	21.8	21.0
.045	.080	.100	.075	14.2	19.0	21.2	18.4	18.2
.035	.030	.060	.040	12.6	11.6	16.4	13.4	13.5
.010	.020	.015	.005	6.7	9.5	8.2	4.7	7.3
.010	.010	.001	.001	6.7	6.7	2.1	2.1	4.4
.001	.001	.001	.000	2.1	2.1	2.1	0.0	1.6
-	-	-	-	-	-	-	-	-

Longitudinal readings every 3".

Average velocity through opening by planimeter = 13.58 ft. per sec.

Corresponding quantity = 81.50 cu. ft. per sec.

Data

for the

Calibration of Three Quarter Opening, 27" x 24".

Test made May 10,1905.

Temperature in Intake 12.8°C. In Duct 19.5°C.

Barometer in Intake 29.37 in. In Duct 29.56 in.

Psychrometer - Wet 58.0°F.- Dry 67.0°F.- Humidity 57.2 %.

Velocity Head (Inches of Water)				Velocity (Feet per Second)				Average Velocity
a	b	c	d	a	b	c	d	abcd
.160	.160	.160	.150	26.9	26.9	26.9	26.0	26.7
.165	.170	.170	.150	27.3	27.7	27.7	26.0	27.2
.160	.165	.172	.150	26.9	27.3	27.8	26.0	27.0
.110	.145	.170	.160	22.3	25.6	27.7	26.9	25.6
.060	.050	.110	.070	16.5	15.0	22.3	17.8	17.9
.020	.025	.003	.010	9.5	10.6	3.7	6.7	7.6
.010	.005	.000	.005	6.7	4.7	0.0	4.7	4.0
.005	.000	.000	.000	4.7	0.0	0.0	0.0	1.2

Longitudinal readings every 3".

Average velocity through opening by planimeter = 16.44 ft. per sec.

Corresponding quantity = 74.00 cu. ft. per sec.

Data

for the

Calibration of One Half Opening, 18" x 24".

Test made May 10,1905.

Temperature in Intake 12.8°C. In Duct 19.4°C.

Barometer in Intake 29.37 in. In Duct 29.56 in.

Psychrometer - Wet 58.5°F.-Dry 67.0°F. Humidity 59.7 %.

Velocity Head (Inches of Water)				Velocity (Feet per Second)				Average Velocity
a	b	c	d	a	b	c	d	abcd
.290	.270	.270	.240	36.2	34.9	34.9	32.9	34.7
.290	.290	.290	.235	36.2	36.2	36.2	32.6	35.3
.170	.220	.270	.230	27.7	31.5	34.9	32.2	31.6
.030	.040	.120	.070	11.6	13.4	23.3	17.8	16.5
.000	.000	.010	.000	0.0	0.0	6.7	0.0	1.7

Longitudinal readings every 3".

Average velocity through opening by planimeter = 22.82 ft. per sec.

Corresponding quantity = 68.50 cu. ft. per sec.

Data

for the

Calibration of One Quarter Opening, 9" x 24".

Test made May 10, 1905.

Temperature in Intake 12.8°C. In Duct 19.8°C.

Barometer in Intake 29.37 in. In Duct 29.56 in.

Psychrometer - Wet 58.0°F. - Dry 67.0°F. Humidity 57.2 %.

Velocity Head (Inches of Water)				Velocity (Feet per Second)				Average Velocity
a	b	c	d	a	b	c	d	abcd
.530	.510	.510	.500	48.8	47.9	47.9	47.5	48.0
.425	.550	.560	.430	43.8	49.8	50.2	44.0	46.9
.190	.460	.500	.370	29.3	45.5	47.5	40.8	40.8
.090	.435	.370	.300	20.1	44.3	40.8	36.8	35.5
.090	.200	.205	.280	20.1	30.0	30.4	35.5	29.0

Longitudinal readings every 1 1/2".

Average velocity through opening by planimeter = 39.10 ft. per sec.

Corresponding quantity = 58.60 cu. ft. per sec.

Data

for the

Calibration of One Eighth Opening, 4 1/2" x 24".

Test made May 10,1905.

Temperature in Intake 12.8°C. In Duct 19.8°C.

Barometer in Intake 29.37 in. In Duct 29.56 in.

Psychrometer -Wet 59.0°F.- Dry 67.5°F. Humidity 60.0 %.

Velocity Head (Inches of Water)				Velocity (Feet per Second)				Average Velocity
a	b	c	d	a	b	c	d	abcd
.890	.940	.870	.820	63.3	65.1	62.6	60.8	62.9
.690	.960	.830	.800	55.8	65.8	61.2	60.1	60.7
.480	.870	.780	.480	46.5	62.6	59.3	46.5	53.7
.260	.720	.700	.280	34.2	57.0	56.2	35 5	45.7
.240	.610	.670	.280	32.9	52.4	54.9	35.5	43.9

Longitudinal readings every 3/4".

Average velocity through opening by planimeter = 53.00 ft. per sec.

Corresponding quantity = 39.70 cu. ft. per sec.

Data

for the

Calibration of One Sixteenth Opening, 2 1/4" x 24".

Test made May 19,1905.

Temperature in Intake 17.0°C. In Duct 26.9°C.

Barometer in Intake 29.57 in. In Duct 29.77 in.

Psychrometer - Wet 72.0°F.- Dry 84.0°F. Humidity 55.6 %.

Velocity Head (Inches of Water)				Velocity (Feet per Second)				Average Velocity
a	b	c	d	a	b	c	d	abcd
1.07	1.07	1.07	1.11	70.1	70.1	70.1	71.4	70.6
.62	1.04	1.06	.60	53.3	69.1	69.8	52.5	61.2
.51	.97	1.02	.38	48.4	66.7	68.5	42.3	56.5

Longitudinal readings every 9/16".

Average velocity through opening by planimeter = 61.50 ft. per sec.

Corresponding quantity = 23.05 cu. ft. per sec.

Data

for the

Calibration of One Thirtysecond Opening, 1 1/8" x 24".

Test made May 19,1905.

Temperature in Intake 17.0°C. In Duct 26.9°C.

Barometer in Intake 29.57 in. In Duct 29.77 in.

Psychrometer - Wet 72.0°F.- Dry 84.0°F. Humidity 55.6 %.

Velocity Head (Inches of Water)				Velocity (Feet per Second)				Average Velocity
a	b	c	d	a	b	c	d	abcd
.90	1.36	1.36	.53	64.3	79.1	79.1	51.6	68.52

One central longitudinal reading.

Average velocity through opening = 68.52 ft. per sec.

Corresponding quantity = 12.87 cu. ft. per sec.

Data

for the

Calibration of Rotary Opening, 10" x 30".

Test made May 21,1905.

Temperature in Intake 18.2°C. In Duct 27.3°C.

Barometer in Intake 29.65 in. In Duct 28.85 in.

Psychrometer - Wet 72.0°F.- Dry 84.0°F. Humidity 55.6 %.

Velocity Head (Inches of Water)			Velocity (Feet per Second)			Average Velocity
a	b	c	a	b	c	abc
.350	.460	.300	40.1	46.0	37.1	41.1
.440	.540	.400	45.0	49.8	42.9	45.9
.420	.520	.300	43.9	48.9	37.1	43.3

Average velocity through opening = 43.4 ft.per sec.

Corresponding quantity =90.5 cu.ft. per sec.

Determination for Air Constant, May 10,1905.

Temperature = 19.5°C. = 67.1°F.

Corrected Barometer reading = 29.56 - .10 = 29.46 in.

Humidity 58.7 %.

Wt. of cu. ft. of dry air 67.1°F.	.0754 lbs.
Wt. of cu. ft. of saturated air at 67.1°F.	.0747 lbs.
Wt. of cu. ft. of air (Hum. 58.7 %)	.0750 lbs.

from Kent page 484.

Wt. of air corrected for barometer reading is

29.46 divided by 29.92 times .0750 = .0740

Wt. of cu. ft. of water at 67.1°F. is 62.4245 lbs.

divided by 1.00162 = 62.32 lbs.

from Kent page 547.

R (ratio) = 62.32 divided by .0740 x 12 = 70.25

$V = 2gRh = 2 \times 32.16 \times 70.25 \times h$

$V = 67.2 \quad h$

Constant = 67.2

Determination of Air Constant, May 19,1905.

Temperature = 26.9°C. = 80.4°F.

Corrected Barometer reading = 29.77 - .10 = 29.67 in.

Humidity 51.2 %.

Similarly to above calculations,

Constant = 67.8

Weights of Air, Vapor of Water, and Saturated Mixtures of Air and Vapor at Different Temperatures, under the Ordinary Atmospheric Pressure of 29.921 in. of Mercury. Table from Kent, page 484.

Temp. Degs. F.	lbs. per cu.ft. of Dry Air	Mixtures of Air Saturated with Vapor. Weight of Cubic Foot of Mixture, lbs.		
		Weight Air	Weight Vapor	Weight Mixture
0°	.0864	.0863	.000079	.086379
12	.0842	.0840	.000130	.084130
22	.0824	.0821	.000202	.082302
32	.0807	.0802	.000304	.080504
42	.0791	.0784	.000440	.078840
52	.0776	.0766	.000627	.077227
62	.0761	.0747	.000881	.075581
72	.0747	.0727	.001221	.073921
82	.0733	.0706	.001667	.072267
92	.0720	.0684	.002250	.070717
102	.0707	.0659	.002997	.068897
112	.0694	.0631	.003946	.067046
122	.0682	.0599	.005142	.065042
132	.0671	.0564	.006639	.063039
142	.0660	.0524	.008473	.060873
152	.0649	.0477	.010716	.058416
162	.0638	.0423	.013415	.055715
172	.0628	.0360	.016682	.052682
182	.0618	.0288	.020536	.049336
192	.0609	.0205	.021542	.045642
202	.0600	.0109	.030545	.041445
212	.0591	.0000	.036820	.036820

Expansion of Water.

The following table, from Kent page 547, gives the relative volumes of water at different temperatures, compared with its volume at 4°C. according to Kopp as corrected by Porter.

Centigrade	Fahrenheit	Volume
4°	39.1°	1.00000
5	41.0	1.00001
10	50.0	1.00025
15	59.0	1.00083
20	68.0	1.00171
25	77.0	1.00286
30	86.0	1.00425
35	95.0	1.00586
40	104.0	1.00767
45	113.0	1.00967
50	122.0	1.01186
55	131.0	1.01423
60	140.0	1.01678
65	149.0	1.01951
70	158.0	1.02241
75	167.0	1.02548
80	176,0	1.02872
85	185.0	1.03213
90	194.0	1.03570
95	203.0	1.03943
100	212.0	1.04332

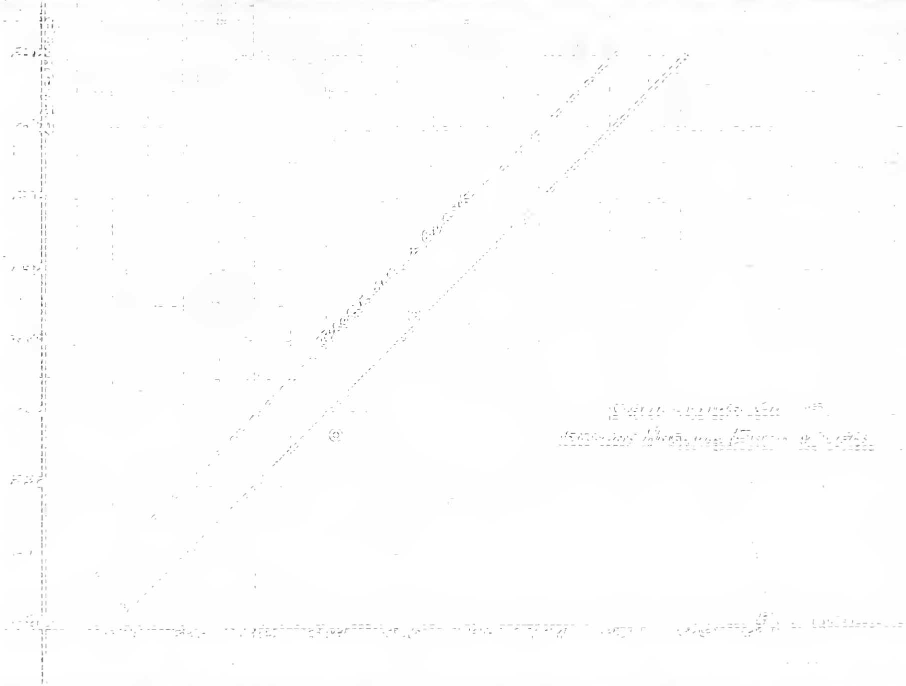
Use of table,

Weight of 1 cu. ft. at any given temperature is equal to the weight of one cu. ft. at 4°C. (62.4245 lbs.) divided by the volume at that temperature.

value over the entire opening.

The draft gauge mentioned previously consists of an aluminum casting 15" X 5" in which a glass tube of the form shown in the blue print is rigidly mounted. The indicating tube has a rise of about one half inch in ten inches, so that the indications on the scale, give the combined fall of the liquid in the reservoir on the left, and the rise of the column in the tube. The tube is calibrated to be read in one hundredths of an inch, and directly in terms of a head of water, although the liquid used is oil, of specific gravity 39.5 Baume, and commercially known as "300 Mineral Seal Oil." Water cannot be used on account of its changing volume due to evaporation, and to the influence of capillary attraction. The limit of the reading of the gauge, if filled to the zero point of the scale, is from zero to one inch pressure head of water, but by filling it to the points marked on the vertical right hand portion of the tube, its capacity may be increased to one and one half or two inches as desired.

In regard to the subsidiary apparatus used, the thermometers were checked both for zero and boiling points by the standard methods, and the intermediate portions of the scale with a standard thermometer, and were found to check within one tenth of one degree. The Green aneroid barometer used was calibrated with a standard mercurial



barometer. The readings were corrected for temperature, and the aneroid was found to read one tenth inch high as can be seen from the accompanying calibration curve.

The Green psychrometer used was checked by means of calcium tubes. The experiment consists of passing a measured amount of air through several "U" tubes connected in series and containing pulverized anhydrous calcium chloride. The tubes are weighed before and after the passage of the air. From the increase in weight of the tubes and the amount of air used the true relative humidity is obtained. By substuting the wet and dry bulb thermometer readings in the psychrometric table appended the humidity as given by the instrument is determined. These values were found to agree very closly. The psychrometer was also checked, with that used by that used by the U.S. Weather Bureau of Chicago, and it was found that no correction need be made. The accompanying table from Kent's "Engineers Handbook" page 483. is that compiled by the U.S. Weather Bureau, and was used for determining the relative humidity from the phychrometer readings.

The principle of the psychrometer action is that the air at any particular humidity will cause a definite evaporation of water, from a small wet cloth slipped over one thermometer bulb, and hence a definite drop in the thermometer reading below that of a dry thermometer. This difference together with the dry thermometer reading will give the relative humidity in per cent of saturation, that is

Relative Humidity in per cent of Saturation.

Table from Kent, page 483, as Compiled by the United States Weather Bureau. Barometer at 30 inches.

Diff. bet. Wet and Dry	Reading of Dry Thermometer in Degrees F.										
	32	40	50	60	70	80	90	100	110	120	140
	Relative Humidity, Saturation being 100.										
1	89	92	93	94	95	96	96	96	97	97	97
2	79	83	87	89	90	91	92	93	93	94	95
3	69	75	80	83	86	87	89	89	90	91	92
4	59	68	74	78	81	83	85	86	87	88	89
5	49	60	67	73	77	79	81	83	84	85	87
6	39	52	61	68	72	75	78	80	81	82	84
7	30	45	55	63	68	72	74	77	78	80	82
8	20	37	49	58	64	68	71	73	75	77	79
9	11	29	43	53	59	64	68	70	73	74	77
10	2	23	38	48	55	61	65	68	70	72	75
11		15	32	43	51	57	61	65	67	69	73
12		7	27	39	48	54	58	62	65	67	70
13		0	21	34	44	50	55	59	62	65	68
14				30	40	47	52	56	60	62	66
15				26	36	44	49	54	57	60	64
16				21	33	41	47	51	55	58	62
17				17	29	38	44	49	52	55	60
18				13	25	35	41	46	50	53	58
19				9	22	32	39	44	48	51	56
20				5	19	29	36	41	46	49	54
21				1	15	26	34	39	44	47	53
22					12	23	31	37	42	45	51
23					9	20	29	35	40	43	49
24					6	18	26	33	38	41	47
26						12	22	28	34	38	44
28						7	17	24	30	34	41
30							13	21	26	31	38

the amount of moisture the air will hold before precipitation occurs.

In order to measure the temperature of the transformer iron, a small coil of insulated wire was inserted between the laminations of the core, and the variations in its resistance were measured by a Wheatstone Bridge. Since the resistance of copper increases .388 per cent per degree, Centigrade, the rise of temperature could be determined.

The preliminary apparatus having been described, the method of proceedure in the main test will now be considered. In making the test the main idea to be brought out was the determination of the proper amount of air required to keep the transformer within the specified temperature limits. Tests were made for quarter, half, three quarters, and full load. From the rise of temperature and the amount of air used, we should have been able to determine how much air should be used to keep the transformer within the specified limits of temperature. The gates used to vary the quantity of air were supposedly fitted into the duct, so that the leakage which might occur around its edges would be negligable. After completing the test, trial computations were made and from the results it was found that the leakage played quite an important part, thus making calculated results inconsistent. The test shows very plainly that there is far too much air supplied, as in no case, with the air cut down as it was, did the transformer rise to its temperature limit.

Data

Showing Temperature Variations, with Transformer under One Quarter Load.

Test made May 17,1905.

Barometer in Intake 29.25 in. In Duct 29.45 in.

Psychrometer -Wet 62.0°F.- Dry 72.0°F. Humidity 56.2 %.

Time	Iron Temp.-Res. Res. Ohms	Temp. Rise	Iron Temp.	Iron Temp. Ther.	Air Temp. Side at Left	at Cent.	at R'h't	Av. Side Temp.	Temp. at Top	Temp. of Room
2.45	9.94	0.0	20.6	20.6	21.6	22.3	21.6	21.8	23.0	27.5
3.00	10.14	4.7	25.3	24.0	24.7	25.1	24.5	24.8	24.0	27.5
3.15	10.25	7.4	28.0	27.8	27.3	27.7	26.9	27.3	24.5	27.5
3.30	10.38	10.3	30.9	31.3	29.4	29.7	28.9	29.3	25.0	28.0
3.45	10.48	12.5	33.1	34.5	31.3	31.3	30.6	31.1	25.5	28.0
4.00	10.57	14.5	35.1	37.6	32.9	32.8	32.2	32.6	25.7	28.0
4.15	10.64	15.9	36.5	39.7	34.0	33.8	33.4	33.7	26.0	28.0
4.30	10.71	17.5	38.1	42.0	35.4	35.1	34.6	35.0	26.2	28.2
4.45	10.78	18.9	39.5	44.0	36.3	35.7	35.5	35.8	26.3	28.2
5.00	10.70	17.3	37.9	42.8	34.6	34.0	33.8	34.1	25.9	28.3
5.15	10.70	17.3	37.9	42.8	34.8	34.4	34.1	34.4	26.0	28.4
5.30	10.78	18.9	39.5	44.6	36.1	35.6	35.2	35.6	26.1	28.3
5.45	10.83	19.9	40.5	46.3	37.1	36.4	36.2	36.6	26.2	28.3
6.00	10.88	20.9	41.5	48.1	37.6	37.5	37.0	37.4	26.3	28.3
6.15	10.95	22.4	43.0	49.9	38.8	38.0	37.5	38.1	26.3	28.5
6.30	10.99	23.2	43.8	50 3	39.3	38.4	38.1	38.6	26.3	28.0
6.45	11.01	23.6	44.2	51.2	39.7	38.7	38.6	38.0	26.3	28.0
7.00	11.02	23.8	44.4	52.1	40.0	38.9	38.8	38.2	26.4	28.0
7.15	11.04	24.1	44.7	52.9	40.4	39.3	39.2	39.6	26.4	27.9
7.30	10.94	22.1	42.7	51.1	38.8	37.8	37.8	38.1	26.0	27.9
7.45	11.00	23.4	44.0	52.0	39.6	38.5	38.4	38.8	26.2	28.0
8.00	11.02	23.8	44.4	52.3	40.0	38.8	38.8	39.2	26.3	28.1
8.15	11.05	24.3	44.9	53.1	40.4	39.2	39.1	39.6	26.4	28.2
8.30	11.07	24.7	45.3	53.8	40.6	39.5	39.4	39.8	26.5	28.3
8.45	11.09	25.1	45.7	54.3	40.9	39.7	39.8	40.1	26.7	28.3
9.00	11.10	25.3	46.0	54.4	41.4	40.1	40.1	40.5	26.8	28.4
9.15	11.12	25.7	46.3	55.3	41.6	40.5	40.4	40.8	26.9	28.5
9.30	11.14	26.1	46.7	55.8	41.8	40.5	40.5	40.9	26.9	28.5

Data

Showing Temperature Variationsbwith Transformer under One Quarter Load,(continued).

Direct Current readings - 1000 amperes - 240 volts.

Alternating Current Readings - 275 K. W. - 9000 volts.

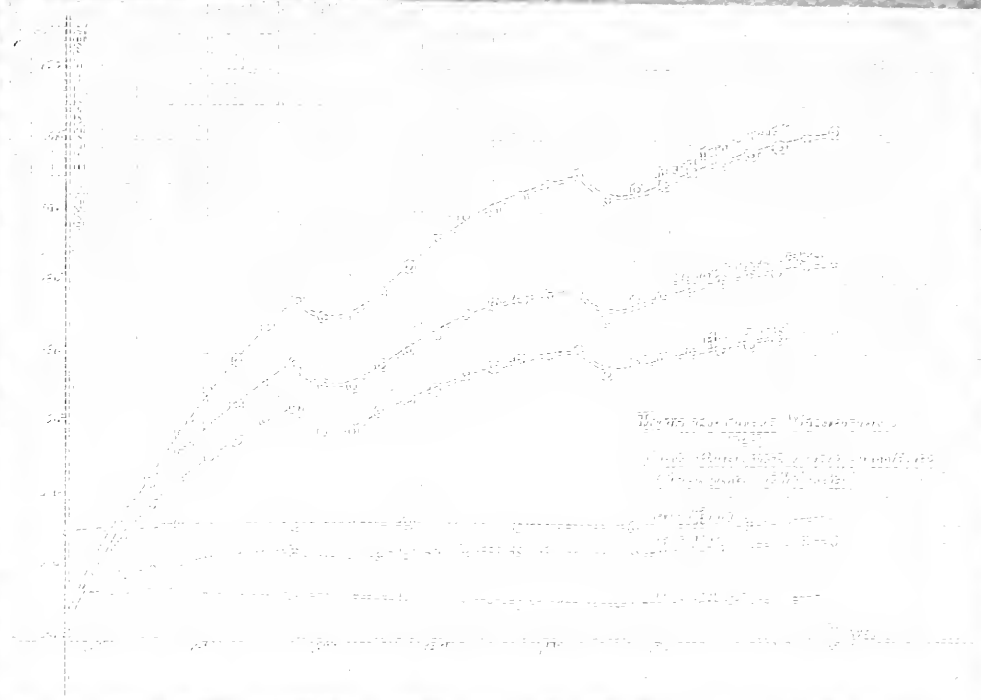
Temperature readings in Duct, degrees C.

Time	2.45	3.45	4.45	5.45	6.45	7.45	8.45
Temp	22.7	23.5	23.3	23.0	22.6	22.6	22.8

Size of Orifice, 2-1/4" x 24".

Rise in Temperature of Secondary Copper.

Time	Res. Sec. Coil	Temp. Rise	Temp.
4.45	.000390 (cold)	----	20.6°C
7.15	.000396	4.0°C	24.6
9.30	.000357	-21.8	----



Data

Showing Temperature Variations, with Transformer under One Half Load.

Test made May 18, 1905.

Barometer in Intake 29.44 in. In Duct 29.65 in.

Psychrometer - Wet 64.5°F. - Dry 77.0°F. Humidity 50.2 %.

	Iron Temp.-Res.			Iron	Air Temp. Side			Av.	Temp.	Temp.
Time	Res. Ohms	Temp. Rise	Iron Temp.	Temp. Ther.	at Left	at Cent.	at R'ht	Side Temp.	at Top	of Room
2.15	10.08	0.0	25.6	25.6	24.7	25.0	25.0	24.9	24.0	26.0
2.30	10.29	5.0	30.6	29.5	26.8	27.0	26.7	26.8	24.5	26.5
2.45	10.41	7.7	33.5	33.0	28.7	29.0	28.4	28.7	25.0	26.5
3.00	10.49	9.5	35.1	35.0	29.7	29.5	29.3	29.5	26.0	26.5
3.15	10.57	11.3	36.7	37.0	31.0	30.5	30.8	30.8	27.1	27.0
3.30	10.62	12.3	37.7	39.0	30.9	31.0	31.3	31.1	27.0	27.0
3.45	10.68	13.6	39.2	40.0	31.4	31.5	32.0	31.6	27.0	27.0
4.00	10.72	14.5	40.1	40.8	32.0	32.0	32.6	32.2	27.0	27.0
4.15	10.77	15.5	41.1	41.0	32.4	32.5	32.9	32.6	27.0	27.0
4.30	10.73	13.8	39.4	38.0	31.6	32.0	31.6	31.7	26.0	26.0
4.45	10.75	15.1	40.7	41.5	31.8	32.0	32.2	32.0	26.8	26.4
5.00	10.81	16.4	42.0	43.0	32.4	32.7	32.8	32.6	27.0	27.3
5.15	10.86	17.4	43.0	44.2	33.2	33.3	33.4	33.3	27.0	27.0
5.30	10.91	18.4	44.0	45.6	33.9	34.0	34.2	34.0	27.4	27.0
5.45	10.94	19.1	44.7	47.0	34.4	34.2	34.6	34.4	27.6	27.0
6.00	10.98	19.9	45.5	47.5	34.6	34.8	35.1	34.8	27.7	27.0
6.15	11.01	20.5	46.1	48.2	35.2	35.1	35.4	35.2	27.7	27.0
6.30	11.03	20.8	46.4	49.3	35.4	35.3	35.7	35.5	27.7	27.0
6.45	10.94	19.1	44.7	47.0	33.4	33.7	34.0	33.7	27.0	27.0
7.00	10.96	19.4	45.0	47.5	34.0	34.0	34.6	34.2	27.2	27.0
7.15	10.98	19.7	45.5	48.0	34.3	34.5	35.0	34.6	27.3	27.0
7.30	11.01	19.5	46.1	48.5	34.7	34.8	35.2	34.9	27.4	27.0
7.45	11.02	20.7	46.3	48.9	34.8	35.0	35.4	35.1	27.7	27.0
8.00	11.04	21.0	46.6	49.2	35.0	35.3	35.7	35.3	27.7	27.0
8.15	11.06	21.4	47.0	49.9	35.6	35.1	35.8	35.5	27.8	27.0
8.30	11.08	21.8	47.4	50.0	35.7	35.3	35.8	35.6	28.0	27.0
8.45	11.08	21.8	47.4	50.2	35.7	35.4	36.2	35.8	28.0	27.0

Data

Showing Temperature Variations with Transformer under One Half Load, (continued).

Direct Current readings - 2000 amperes - 240 volts.

Alternating Current readings - 550 K. W. - 9000 volts.

Temperature readings in Duct, degrees C.

Time	2.15	3.15	4.15	5.15	6.30	7.45
Temp.	22.0	21.6	21.3	20.9	20.4	20.8

Changes in size of orifice.

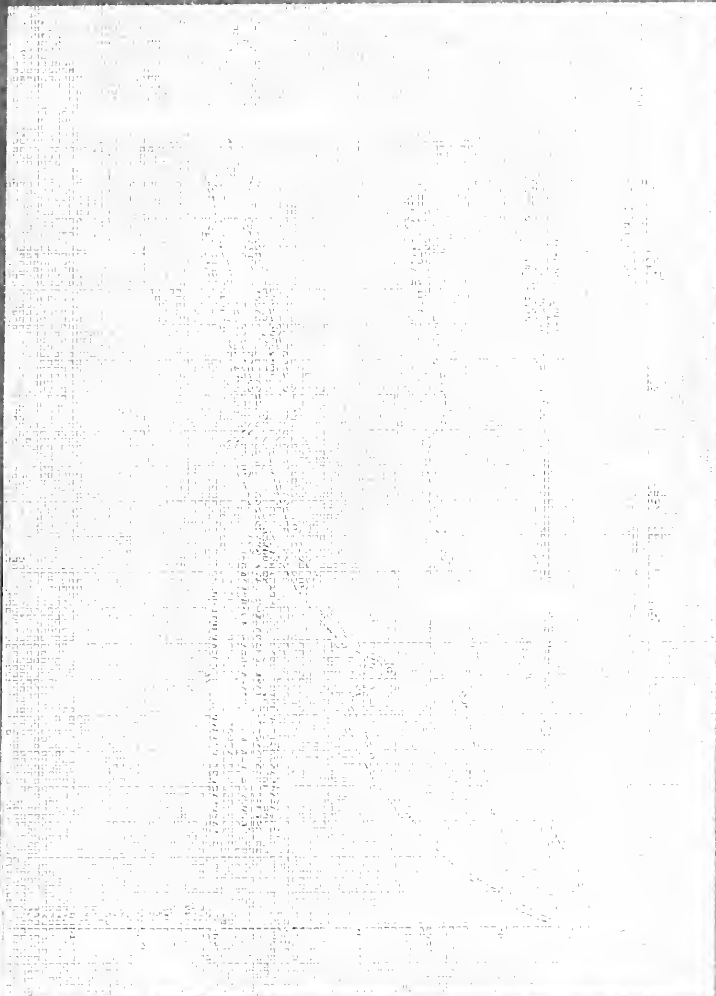
2.15 to 4.15 P.M., 3-3/8" x 24" opening.

4.15 to 8.45 P.M., 1-1/8" x 24" opening.

Rise in Temperature of Secondary Copper.

Time	Res. Sec. Coil	Temp. Rise	Temp.
1.50	.000366(cold)	----	25.6°C
4.15	.000356	-7.0°C	18.6
6.30	.000356	-7.0	18.6
8.45	.000360	-4.2	21.4

Note:- Readings inconsistent, due to the inductance of the coil.



Data

Showing Temperature Variations with Transformer under

Three Quarter Load

Test made May 19,1905.

Barometer in Intake 29.56 in. In Duct 29.76 in.

Psychrometer - Wet 71.0°F.- Dry 84.0°F. Humidity 52.0 %.

Time	Iron Temp.-Res. Res. Ohms	Temp. Rise	Iron Temp.	Iron Temp. Ther.	Air Temp. Side at Left	at Cent.	at R'ht	Av. Side Temp.	Temp. at Top	Temp. of Room
3.15	10.20	0.0	29.0	29.0	29.2	29.0	28.6	28.9	29.1	28.5
3.30	10.35	3.7	32.6	31.3	30.8	30.8	30.2	30.6	30.8	29.0
3.45	10.45	6.9	35.9	34.2	32.6	32.8	31.2	32.2	32.2	29.0
4.00	10.61	10.0	39.0	37.6	34.8	35.4	32.0	34.1	34.0	29.0
4.15	10.70	12.1	41.1	41.0	36.1	37.0	32.8	35.5	34.9	29.5
4.30	10.79	14.1	43.1	43.4	37.4	38.3	33.5	36.4	35.9	29.5
4.45	10.89	16.3	45.3	37.3	38.5	39.6	33.9	37.3	36.3	29.5
5.00	10.94	17.4	46.3	48.0	39.5	40.4	34.2	38.0	36.8	29.8
5.15	11.00	18.8	47.8	49.5	40.3	41.4	34.6	38.8	37.2	30.0
5.30	10.93	17.2	46.2	48.4	39.0	39.8	33.0	37.3	35.4	29.5
5.45	11.03	19.4	48.4	50.4	40.5	41.3	34.6	38.8	36.5	30.0
6.00	11.09	20.7	49.7	51.8	41.3	42.0	34.7	39.3	37.0	30.0
6.15	11.15	22.0	51.0	53.3	42.2	43.0	35.4	40.2	37.4	30.0
6.30	11.18	22.6	51.6	54.5	42.7	43.8	35.6	40.7	37.7	30.5
6.45	11.22	23.5	52.5	55.7	43.3	44.5	39.9	42.6	38.0	30.5
7.00	11.26	24.3	53.3	56.7	43.8	45.0	40.3	43.0	38.6	30.5
7.15	11.29	25.0	54.0	57.7	44.2	45.3	40.6	43.4	38.7	30.5
7.30	11.31	25.3	54.3	58.5	44.5	45.8	40.8	43.4	38.8	30.5
7.45	11.22	23.5	52.5	56.4	43.0	43.8	39.8	42.2	37.0	30.7
8.00	11.25	24.1	53.1	57.1	43.6	44.4	40.0	42.5	37.5	31.0
8.15	11.28	24.7	53.7	57.8	44.1	45.0	40.3	43.1	38.0	31.2
8.30	11.30	25.1	54.1	58.0	44.4	45.5	40.7	43.5	38.7	31.2
8.45	11.34	25.9	54.9	59.0	44.8	46.0	40.9	43.9	39.0	31.5
9.00	11.35	26.1	55.1	59.7	45.2	46.3	41.2	44.2	39.3	31.5
9.15	11.36	26.3	55.3	60.1	45.6	47.0	41.6	44.7	39.7	31.5
9.30	11.38	26.7	55.7	60.8	45.8	47.3	41.8	45.0	39.9	32.0
9.45	11.40	21.2	56.2	61.0	46.0	47.4	42.0	45.1	39.9	32.0

Data

Showing Temperature Variation with Transformer under Three Quarter Load (continued).

Direct Current readings - 3000 amperes - 240 volts.

Alternating Current readings - 825 K. W. - 9000 volts.

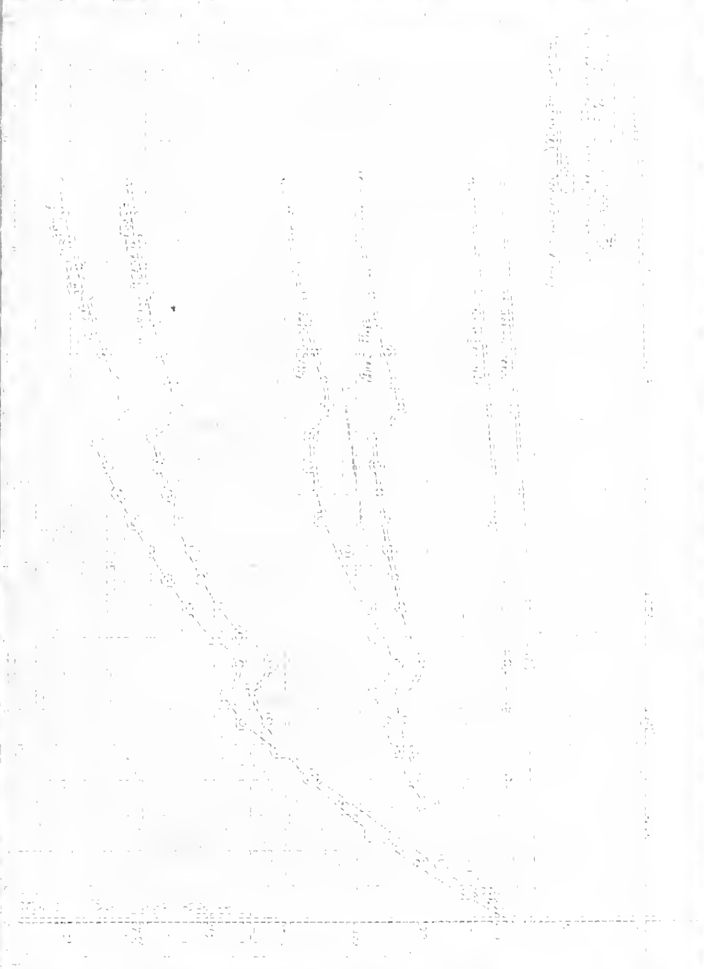
Temperature readings in Duct, degrees C.

Time	3.00	5.15	7,30	9.45
Temp.	27.7	27.9	29.1	29.5

Size of Orifice 1 1/8" x 24".

Rise in Temperature of Secondary Copper.

Time	Res. Sec. Coil	Temp. Rise	Temp.
3.00	.000356 (cold)	-----	29.0°C
5.15	.000375	13.8°C	42.8
7.30	.000384	20.3	49.3
9.45	.000382	18.8	47.8



Data

Showing Temperature Variation with Transformer under Full Load.

Test made May 24,1905.

Barometer in Intake 29.32 in. In Duct,(no cooling air) 29.30 in.,(air on) 29.52 in.

Psychrometer - Wet 69.5^{O}F.- Dry 80.5^{O}F. Humidity 57.0 %.

	Iron Temp.-Res.			Iron	Air Temp. Side			Av.	Temp.	Temp.
Time	Res. ohms	Temp. Rise	Iron Temp.	Temp. Ther.	at Left	at Cent.	at R'ht	Side Temp.	at Top	of Room
8.30	10.33	0.0	30.0	30.0	28.8	29.2	28.4	28.8	28.5	28.0
8.45	10.50	4.2	34.2	34.0	31.8	32.0	30.6	31.5	30.6	28.8
9.00	10.67	8.2	38.2	37.6	34.6	35.0	33.5	34.4	33.5	29.4
9.15	10.85	12.4	42.4	41.7	37.7	37.0	36.2	37.1	37.0	29.5
9.30	11.00	15.7	45.7	45.3	40.4	39.6	38.5	39.5	39.6	28.7
9.45	11.16	19.2	49.2	49.4	42.6	42.5	40.8	42.0	41.0	30.0
10.00	11.32	22.5	52.5	53.3	45.0	43.5	42.1	43.5	42.6	30.2
10.15	11.48	25.8	55.5	56.9	46.9	44.0	43.9	44.9	44.0	30.5
10.30	11.64	29.0	59,0	60.2	48.8	46.5	45.2	46.8	46.5	30.2
10.45	11.65	29.2	59.2	61.2	49.3	48.2	48.5	42.0	47.3	30.3
11.00	11.44	25.0	55.0	60.3	48.8	50.5	44.7	48.0	44.3	30.4
11.15	11.42	24.6	54.6	61.0	48.2	50.0	44.3	47.5	42.8	30.9
11.30	11.43	24.8	54.8	61.3	47.8	49.5	44.2	47.2	41.7	31.4
11.45	11.44	25.0	55.0	61.6	47.6	49.4	44.2	47.1	41.2	31.3
12.00	11.45	25.2	55.2	61.8	47.5	49.4	44.2	47.0	41.0	31.6
12.15	11.45	25.2	55.2	61.9	47.4	49.1	44.1	46.9	41.0	32.0
12.30	11.45	25.2	55.2	62.0	47.2	49.0	44.0	46.7	40.7	32.3
12.45	11.44	25.0	55.0	61.9	47.2	49.0	44.1	46.8	40.9	32.4
1.00	11.44	25.0	55.0	61.9	47.2	49.0	44.2	46.8	41.0	32.9
1.15	11.45	25.2	55.2	61.3	45.6	47.5	42.8	45.3	38.8	32.2
1.30	11.29	21.9	51.9	58.6	43.8	45.2	41.8	43.6	38 2	32.5
1.45	11.27	21.5	51.5	58.3	44.0	45.4	41.9	43.8	38.0	33.2
2.00	11.26	21.3	51.3	58.0	44.1	45.4	41.9	43.8	38.2	33.7
2.15	11.26	21.3	51.3	58.0	44.2	45.5	41.9	43.9	38.4	33.7
2.30	11.26	21.3	51.3	58.0	44.2	45.4	41.9	43.8	38.3	33.7
2.45	11.26	21.3	51.3	58.0	44.1	45.5	41.9	43.8	38.5	33.5
3.00	11.26	21.3	51.3	58.0	44.0	45.3	41.9	43.7	38.5	34.0
3.15	11.33	22.8	52.8	57.2	43.2	45.0	41.2	43.1	36.8	33.3
3.30	11.16	19.2	49.2	55.4	41.4	42.1	39.6	41.0	36.0	33.3
3.45	11.14	18.7	48.7	55.1	41.5	42.4	39.7	41.2	36.4	33.5
4.00	11.14	18.7	48.7	55.0	41.6	42.3	39.7	41.2	37.0	33.5
4.15	11.14	18.7	48.7	54.8	41.6	42.5	39.0	41.2	37.2	33.7
4.30	11.14	18.7	48.7	54.8	41.6	42.6	39.6	41.2	37.5	33.8

Data

Showing Temperature Variations with Trans former under Full Load (continued).

Direct Current readings - 4000 amperes - 240 volts.

Alternating Current readings - 1100 K. W. - 9000 volts.

Readings in Duct.

Time	Temp. Degrees C.	Barometer
8.30	26.1	29.30
10.30	26.5	29.52
12.00	26.9	29.52
1.15	27.1	29.52

Changes in Size of Orifice.

8.30 to 10.45, zero opening.

10.45 to 1.00, 1-1/8" x 24". opening.

1.00 to 3.00, 2-1/4" x 24" opening.

3.00 to 4.30, 4-1/2" x 24" opening.

Rise in Temperature of Secondary Copper.

Time	Res. Sec. Coil	Temp. Rise	Temp.
8.30	.000353(cold)	----	30.0°C
10.30	.000418	47.5°C	77.5
1.00	.000376	16.8	46.8
3.00	.000379	19.0	49.0
4.30	.000372	13.9	43.9

Note:- The resistance of copper increases .388 %, per degree, Centigrade.

Commutator rise after run 67.2°C.

The rotary was kept at the load determined upon, by means of the direct current switchboard ammeter. Thermometer readings were taken every fifteen minutes at the following points; three places on the side of the transformer; on the transformer iron; at the top of the transformer; in the duct and in the room. At intervals of about two hours during the test the machine was shut down, and the resistance of a coil of the transformer secondary was measured by connecting it in series with a lamp rack, between the positive station bus and the transformer neutral. The current through the coil and the drop over it were measured, and thus the resistance was calculated. From the change in resistance, the rise in temperature of the secondary copper could be determined. These readings were not entirely sucessful, since the inductance of the coil made the pressure reading very slow in coming to constant values.

In the first part of the full load test the transformer was run without any cooling air for two hours with a resulting rise which was well within the specified limit of 40° C. as is shown on the data sheet.

If this sort of a test were to be performed again it could be carried on much more successfully if the gates were dispensed with entirely. The opening could then be calibrated as it stands with various conditions of duct pressure, making these variations by changing the blower speed.

In this way all leakage would be avoided and actual running conditions be obtained, and from the results the exact size of the blowing equipment would follow.

A test on the blower was made with this end in view, but the leakage mentioned prevents the direct application of these results, although in themselves they are quite interesting. The test was made by inserting a lamp rack as a variable resistance in the armature circuit of the blower motor, in order to vary its speed within a wide range. The gates were set for one quarter opening, and the Pitot tubes placed in such a position that from the gauge readings and the quarter opening calibration the velocity and quantity of air passing through could be determined. Readings were made of the draft gauge, temperature, and barometric pressure in and out of the duct; and the speed and power consumption of the blower. The accompanying data and curves of this test show the variation of the quantity of air with the speed of the blower, with the static pressure of the duct, and with the kilo-watt consumption. An interesting feature was noted, when both blowers were run together, one having a slightly greater amount of power delivered to it, and hence creating a greater pressure, thus forcing the air backwards against the fans of the other blower, with the result that the static pressure of the duct and the quantity of air delivered was less than when one motor was running alone.

Data.

for the

Test on Blower # 1, General Electric Motor # 81277,

Class 4 - 35 H.P.- 600 R.P.M.

Test made May 26,1905.

Gates at One Quarter Opening, 9" x 24".

Temperature in Intake 10.1°C. In Duct 14.9°C.

Barometer in Intake 29.62 in.

Psychrometer - Wet 55.9°F.- Dry 61.9°C.

Fields - 240 Volts - 1.7 Amperes - 0.4 Kilo Watts.

Constant for Air Readings 67.6.

Motor RPM	Arma. Volts	Total Amps.	Total K.W.	Bar. Duct	Bar. Dif.	Oz.per Sq.In.	Vel. Head	Cor. Vel.	Av. Vel.	Av. Quan
284	117	17.4	2.2	29.67	.05	.392	.120	23.4	18.7	28.0
323	134	21.1	3.0	29.68	.06	.471	.160	27.0	21.5	32.2
368	152	24.9	3.9	29.70	.08	.628	.220	31.7	25.3	37.9
405	167	28.7	4.9	29.72	.10	.785	.255	34.1	27.2	40.8
434	173	31.1	5.5	29.73	.11	.863	.290	36.4	29.0	43.5
595	240	52.8	12.8	29.82	.20	1.570	.560	50.6	40.3	60.5